Journal of Traffic and Transportation Engineering 8 (2020) 93-105
doi: 10.17265/2328-2142/2020.03.001

# Preliminary Investigation on Establishing a New Resilient Modulus Test Approach for Reduced Size Asphalt Mixture Samples Smaller Than 100 mm Diameter

Ratnasamy Munaindy, Francis Xavier, Fauzan Jakarni and Salihudin Hassim

*Department of Civil Engineering, Universiti Putra Malaysia, Serdang, Seri Kembangan 43400, Malaysia*

**Abstract:** The performance evaluation of existing flexible pavements has become a priority issue for many highway maintenances engineers. To make appropriate rehabilitation and management decisions, the engineers most often rely on efficient methods for the determination of the strength of pavement layers. Resilient modulus is a very important parameter to be identified and used in pavement design. The resilient moduli of asphalt mixtures are typically measured using the indirect tension test procedure in compliance with the ASTM D4123 standard that is superseded by ASTM D7369. The standard requirement is that the prepared specimens for the tests should have a minimum height of the sample over its diameter ratio of 0.4. Generally, specimens used in the tests are either a nominal 100 mm or 150 mm in diameter with a minimum thickness over diameter ratio of 0.4. However, 100 mm diameter core specimens taken from site wearing courses with thicknesses ranging from 40 mm to 50 mm most often do not fulfil the minimum ratio of 0.4 after they are trimmed for testing. Since there was no any option, part of the binder courses had to be trimmed to make up for the minimum ratio requirement. This tends to result in inaccurate assessment of the resilient modulus values of the samples. As such, a new procedure was explored to test specimens smaller than 100 mm in diameter. This may minimize the material volume requirement from the field and also for the fabrication of smaller samples in the laboratory. Based on the available thickness of wearing course or overlay, the appropriate sizes were determined. For a two-layer system a 56.3 mm diameter was deemed necessary while a 37.5 mm diameter was observed to be appropriate for a three-layer system. Such an approach for resilient modulus test using miniature specimens of 56.3 mm and 37.5 mm in diameter has a great potential for practical relevance for the industry.

**Key words:** Resilient modulus, new procedure, cost, time and less destructive.

## 1. Introduction

Resilient modulus is an important parameter that is used to quantify the strength of asphalt pavement layers. Asphalt pavements are designed to undertake different types of design axles such as single, couple, and tridem load applications and are based on the resilient modulus of the asphalt mixture materials or the asphalt layers. Appropriate use of resilient modulus in designing asphalt pavements may assure the required load bearing capacity of road pavements and thus increase their life span [1]. Falling Weight Deflectometers (FWD) are commonly used to measure the structural conditions flexible pavement layers in terms of resilient modulus. The results of resilient modulus values for flexible pavement layers acquired from the back-calculation analysis tend to be not very precise despite the fact that the measured and calculated deflection may remain within acceptable parameters [2]. Wide interpretation is associated with getting the resilient modulus of these flexible pavement layers. FWD interpretation has turned out to be more demanding, since more of our flexible pavements have encountered various milling processes and overlays. The properties of a structure

**Corresponding author:** Ratnasamy Muniandy, Ph.D., professor, research fields: asphalt, pavement and recycled materials.

in terms of damaged layers, thickness variety and temperature differences can affect the pavement layer deflection values, having a much more critical impact than those made by structural layer stiffness.

A study was undertaken at Universiti Putra Malaysia to develop a new procedure to carry out resilient modulus testing on cored specimens from field overlay, wearing course or laboratory fabricated asphalt mixture. These new findings may allow researchers and practitioners to perform resilient modulus test on specimens smaller than the traditional 100 mm and 150 mm in diameter specimens while maintaining reasonable equivalence to the standard test procedure as per ASTM D4123. The new approach may drastically reduce the amount of asphalt and aggregate materials for mix design and testing. Display quotations of over 40 words, or as needed.

### *1.1 Dimension Requirements of Specimen*

A lot of development and research were carried out on the use of resilient modulus and dynamic modulus of hot mix asphalt as material properties to be used in the flexible pavement design [3]. Those studies showed that the size of the sample mathematically influenced the obtained resilient modulus of the particular samples. The resilient modulus values acquired for the 100 mm diameter samples were higher than those obtained for the 150 mm diameter samples in all variable temperatures used for carrying out the testing [4]. Fig. 1 shows the effects of the two specimen diameters.

Kandhal [5] did a similar assessment on 100 mm and 150 mm diameter samples and found that the resilient modulus values of the 6-inch (150 mm) diameter samples were lower than the 100 mm diameter samples. Under a similar loading condition, the strain rate for the 150 mm diameter samples was lower than that of the 100 mm samples [3].

In addition, Lim et al. studied various sample size and observed that there is an impact on the after-effects of diametrical mechanical testing approaches, in particular the resilient modulus and indirect tension tests. The diameter over height ratio of sample was consistent at 1.6 and it was found that the resilient modulus values decreased as the diameter of the sample increased [6].

There are indications in the Australian Standard AS 2891.13.1, that the thickness of the test samples is to be in the vicinity of 70 mm and 35 mm thick for 100 mm diameter samples while the 150 mm diameter samples should be in the vicinity of 90 mm and 60 mm thick [7]. Hugo and Schreuder assessed the impact of the sample thickness on the tensile strength and related engineering practices using the static Indirect Tensile Test. According to them they found that the indirect tensile strength increased as the

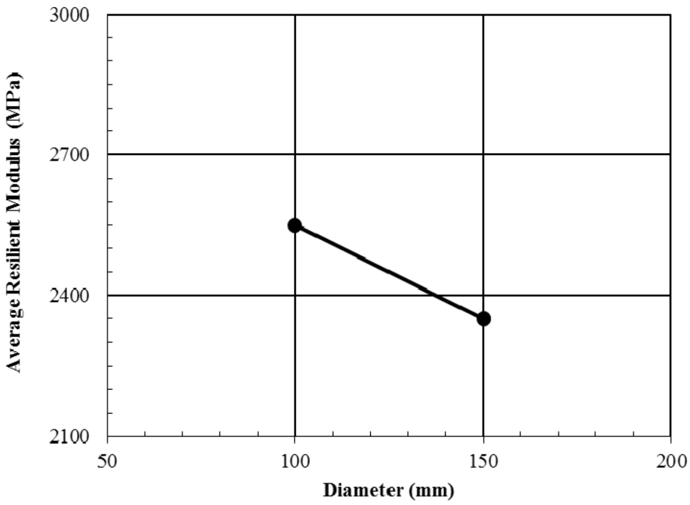



**Fig. 1 Effect of specimen diameter [9].**

sample thickness of the samples [8]. The samples with thickness more than 20 mm will be experiencing stress concentrations at the bottom and top of the contact surface. The stress along the rest of the vertical diameter would be diminished far beneath the average calculated stress level [5]. This could be the reason for the expansion in tensile strength, considering the way that the unequal pressure dissemination makes the sample quality pressure-reliant. This was observed to be in the middle part of the samples once the uppermost and the base contact points (much pressured points) outwardly tend to fail [10].

### *1.2 Maximum Nominal Aggregate Size*

The Australian Standard AS 2891.13.1 suggests that samples with particle size up to 40 mm can be used in the determination of resilient modulus value. A preliminary investigation by Lim et al. on the impact of diameter and nominal aggregate size proportion demonstrated that the resilient modulus values of samples decreased as the proportion of maximum nominal size of aggregate increased [9].

Research carried out by Brown and Bassett on the relationship between asphalt blend properties and stone sizes showed a strong relationship between the resilient modulus and the various stone sizes. In addition, the resilient modulus value increased as the stone size increased [11]. Fig. 2 shows the effect of maximum nominal aggregate size on the resilient modulus value.

Many researchers carried out studies to explore the effect of the material properties of the significant segment on the resilient modulus values of asphalt blends with the coarse stone texture considered as the main factor [12]. The resilient modulus studies carried out at a temperature of 25 °C, using coarse aggregates with more irregular morphologies significantly enhanced the resilient modulus of asphalt blends [13].

### *1.3 Resilient Modulus Characterization*

The resilient modulus values of asphalt mixtures are practically equivalent to Young's modulus of flexibility for direct flexible materials. In reality, pavement materials are not versatile, which implies that they definitely result in some permanent deformation after each load cycle. The strain in viscoelastic materials can be isolated into the versatile strain, likewise called the resilient strain and the viscous stain. In this scenario, only the resilient strain is recovered after the load is expelled [14].

In addition, cored asphalt mixture specimens from slabs prepared using an automatic roller compactor were used in the determination of resilient modulus. This however showed a more consistent airvoids

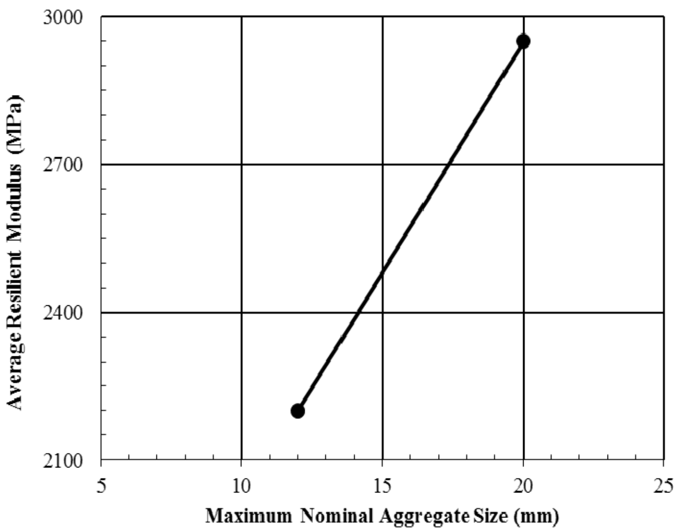



**Fig. 2 Effect of maximum nominal aggregate size on the resilient modulus [9].**

contents in the asphalt mixture specimen as compared with specimens compacted using a Marshall compactor [15].

*1.4 Resilient Modulus Test*

The ASTM D4123 calls for a five-pulse indirect tensile modulus test to determine the stiffness values of compacted asphalt mixtures. In the test, a pulsed diametral loading force is applied to a specimen. The resulting total recoverable diametral strain is then measured from the axes 90 degrees from the applied force. Strain in the same axis is not measured and thus a value of 0.4 for Poisson's ratio is used as a constant. With a fixed level of applied peak force, the test sequence consists of the application of 150 conditioning pulses followed by 5 pulses where data acquisition takes place. The conditioning pulses ensure that the loading plates are seated onto the specimen for consistent results. For controlled temperature testing, the specimen's skin and core temperatures are estimated by transducers inserted in a dummy specimen and located near the specimen under test. The laboratory fabricated specimens or cored specimens from the site are mounted in the indirect tensile test jigs and the results are recorded in a computer.

## 2. Materials and Method

Pavement materials selected for the study are granite aggregate and 80-100 penetration asphalt binder. Both the materials fulfilled the local road construction specification and were used in the design of Hot Mix Asphalt Mixture 14 (HMA14) with a maximum nominal aggregate size of 14 mm. The selected gradation envelope and desired gradations are as shown in Fig. 3. The 80-100 penetration asphalt binder was tested for its viscosity using a Brookfield Rotational viscometer. The mixing and compaction temperatures were estimated to be in the range of 154-160 °C and 141.0-146.5 °C respectively. These are shown in Fig. 4 and Table 1 below. The mix design was carried out using Marshall Mix design approach in accordance with ASTM D1559. A total of 15 samples were made with a binder content range of 4.0 to 6.0% at an increment of 0.5%. Additional 5 loose samples were prepared at the specified binder content for the determination of Theoretical Maximum Density (TMD) using the RICE Method in accordance with ASTM D2041.

The Optimum Asphalt Content (OAC) was determined to be 5.56% using the Asphalt Institute (AI) Method. The HMA14 mixture properties such as stability, flow, Voids in Total Mix (VTM), Voids in Filled with Asphalt (VFA), resilient modulus, bulk density and Voids in Mineral Aggregates (VMA) were determined to be 8.4 kN, 3.18, 4.8%, 64.4%, 1,758 MPa, 2.30 and 17.4% respectively. These are shown in Table 2 below.

*2.1 Design and Fabrication of Specimen and Test Assembly*

As explained in the prior sections that, most often the core samples from the site overlay or wearing course layers tend to be insufficient in thickness

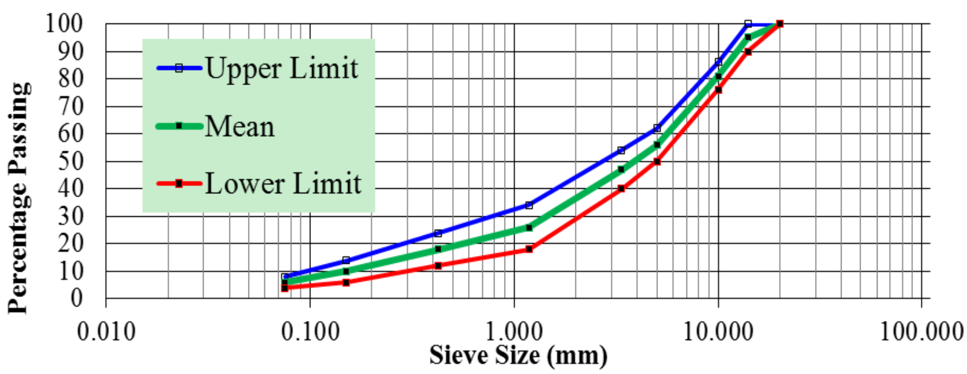



**Fig. 3 Selected gradation specification for HMA14.**

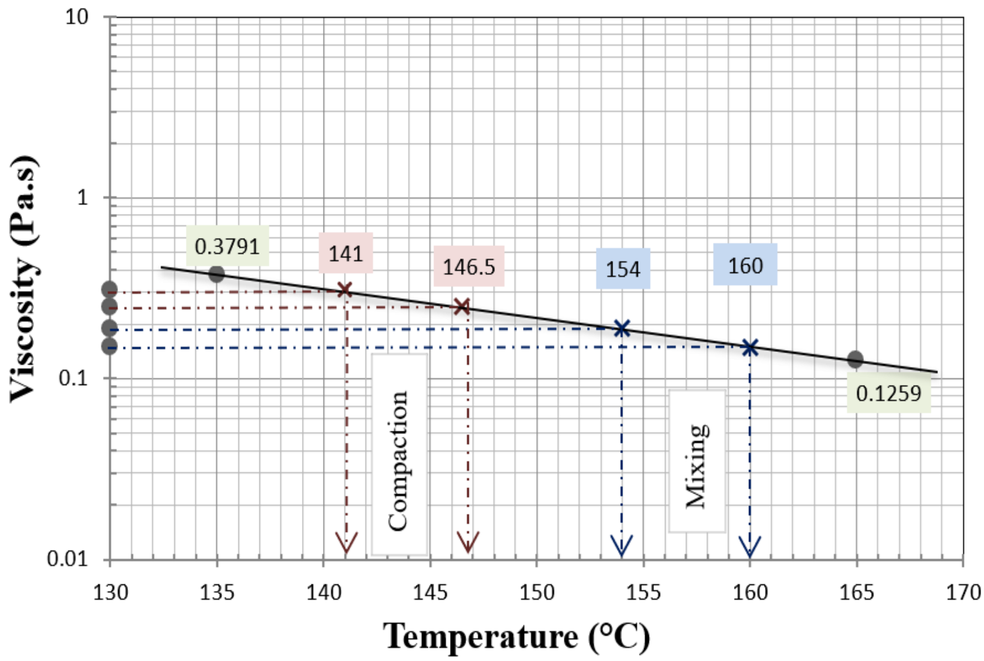



**Fig. 4 Mixing and compaction temperature.**

**Table 1 Mixing and compaction temperatures.**

| Description | Minimum | Maximum |
|---|---|---|
| Mixing | 154 °C | 160 °C |
| Compaction | 141 °C | 146.5 °C |

**Table 2 HMA14 mix design properties.**

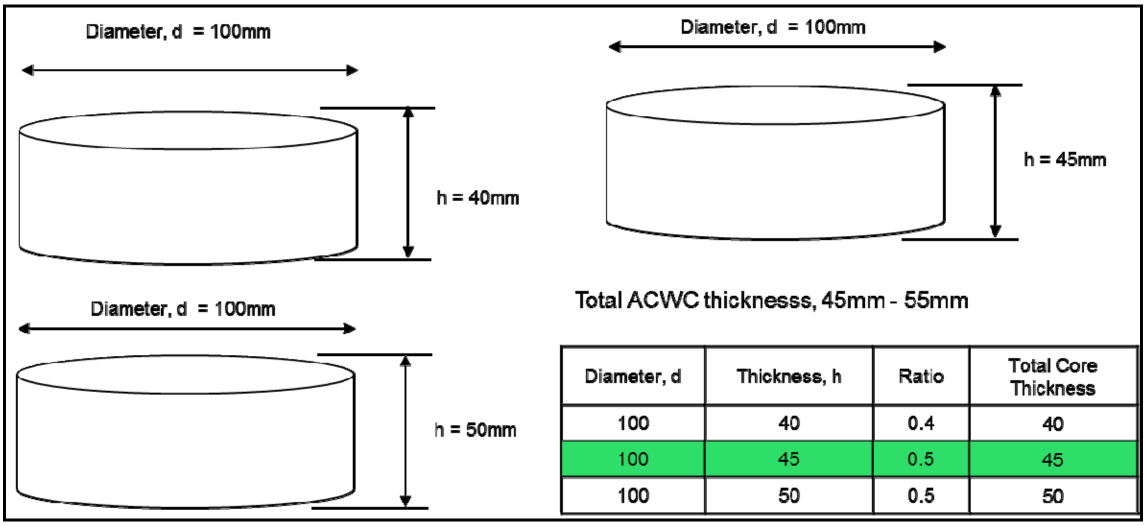
| Property | Value at OAC | Requirements | Compliance |
|---|---|---|---|
| Stability (N) | 8,424 | > 8,000 | OK |
| Flow (mm) | 3.18 | 2.0-4.0 | OK |
| Air voids in total mix (%) | 4.80 | 3.0-5.0 | OK |
| VFA (%) | 64.44 | 70-80 | OK |
| Resilient modulus (Mpa) | 1,758 | Not required | - |
| Bulk density (kg/mm$^3$) | 2.30 | Not required | - |
| VMA (%) | 17.37 | Not required | - |

requirement after trimming the samples. The minimum thickness over diameter ratio tends to be below 0.4. As such, reduced sample sizes were determined based on the typical overlay and wearing course layer thickness ranging from 40-50 mm.

*2.2 Establishment of Sample Thickness and Diameter*

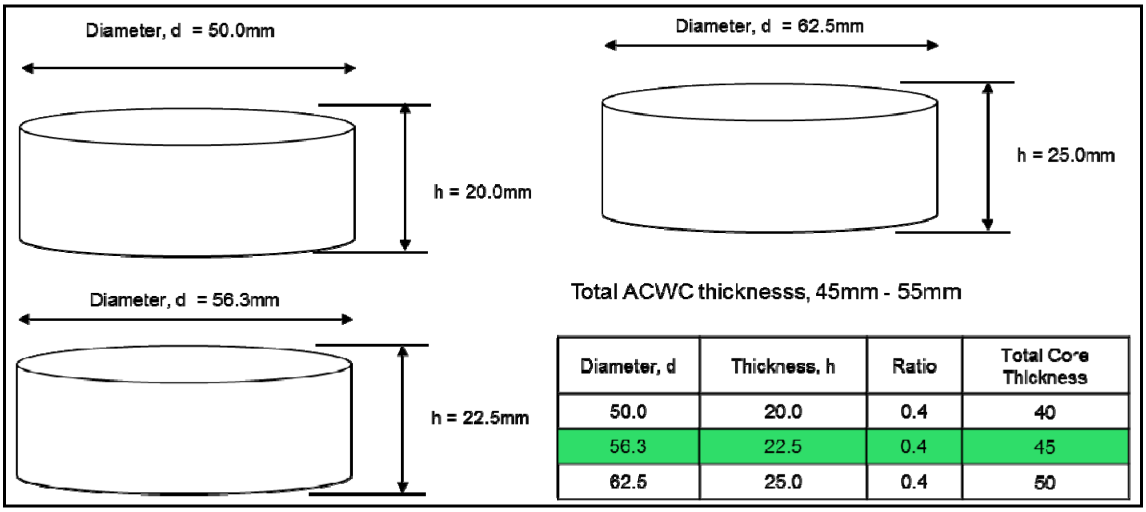
A two-layer and three-layer core slice approach was taken into consideration in the determination of reduced sample diameters. The intention is to fabricate a good number of smaller samples for the establishment of the new resilient modulus test procedure. Based on the selected 50, 56.3 and 62.5 mm diameter, calculations showed that the 56.3 mm could provide 2 sliced and cored samples with a minimum thickness of 22.5 mm as shown in Fig. 5.

In establishing a new protocol for reduced sample size resilient modulus, the two main variables are pulse width and applied loading. Therefore, a total of 75 (5 pulse × 5 loading × 3 replicas) samples were required for each selected diameter of 100 mm, 56.3 mm and 37.5 mm with a total of 225 samples. The minimum thickness of samples was determined based on the 0.4 ratio of height over diameter for each 100 mm diameter sample.




| Diameter, d | Thickness, h | Ratio | Total Core Thickness |
|---|---|---|---|
| 100 | 40 | 0.4 | 40 |
| 100 | 45 | 0.5 | 45 |
| 100 | 50 | 0.5 | 50 |

**Fig. 5 Calculated minimum thickness for 100 mm diameter sample.**




| Diameter, d | Thickness, h | Ratio | Total Core Thickness |
|---|---|---|---|
| 50.0 | 20.0 | 0.4 | 40 |
| 56.3 | 22.5 | 0.4 | 45 |
| 62.5 | 25.0 | 0.4 | 50 |

**Fig. 6 Calculated minimum thickness for 56.3 mm diameter sample.**

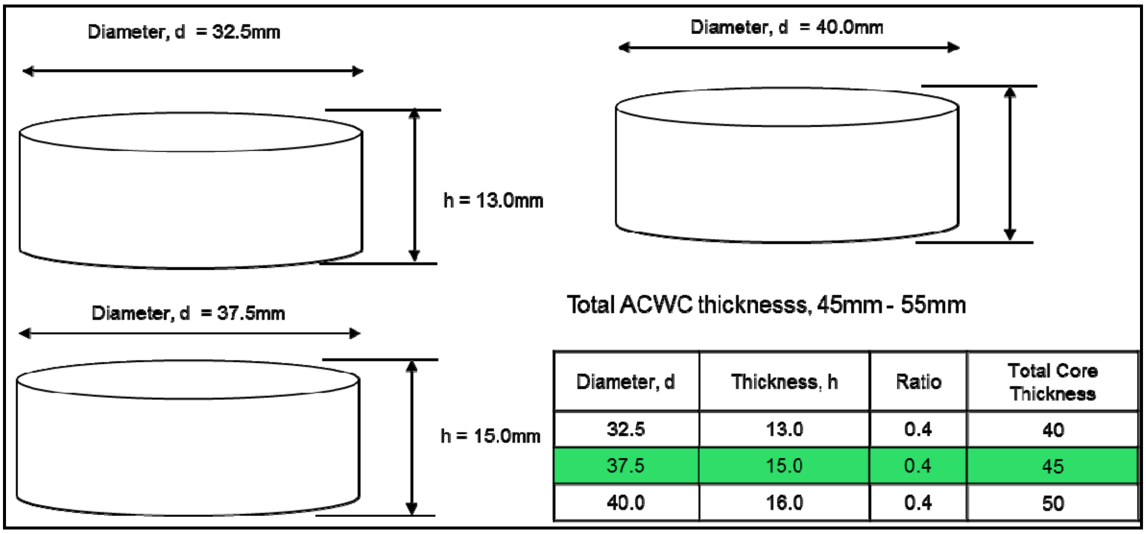
Fig. 6 shows the calculated minimum thickness for the 56.3 mm diameter sample. For the 3-layer system, 32.5, 37.5 and 40 mm diameters were considered and 37.5 mm diameter was selected since 3 samples could be trimmed and sliced from the site overlay and wearing course thickness range of 40-50 mm.

Fig. 7 shows the calculated minimum thickness for 37.5 mm diameter sample.

*2.3 Coring on 150 mm Diameter Gyratory Compacted Samples*

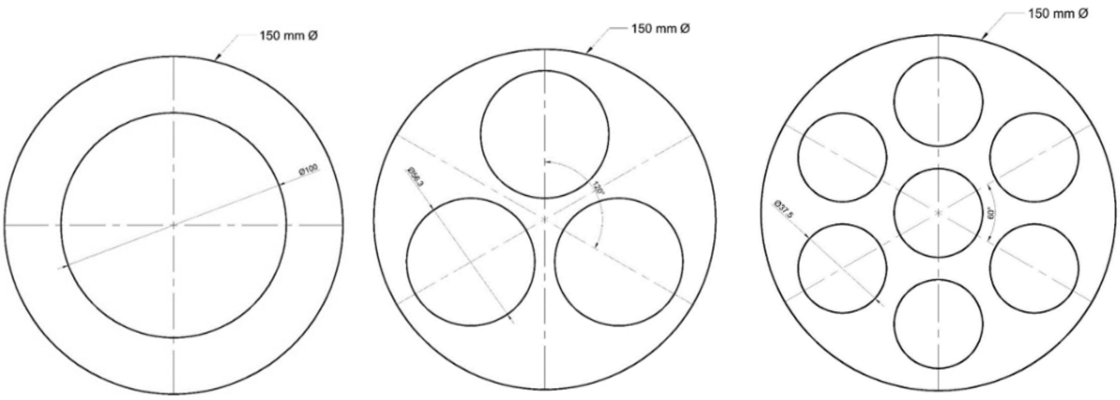
To ensure consistency the fabrication of the various diameter size samples, several 150 mm diameter samples were made using the superpave gyratory with a predetermined OAC of 5.56%. Three specific coring templates were designed to ensure homogeneity and spread of the extracted samples from the original 150 mm diameter compacted samples. The template designs are as shown in Fig. 8.

The cored 100, 56.3 and 37.5 mm samples were sliced to its required thickness. During slicing, the samples have to be again labelled from top to bottom and on the top surface of each sample using a planned labelling method using permanent markers to ensure that the samples can be traced back to the original samples to minimize any discrepancies during the performance study.




| Diameter, d | Thickness, h | Ratio | Total Core Thickness |
|---|---|---|---|
| 32.5 | 13.0 | 0.4 | 40 |
| 37.5 | 15.0 | 0.4 | 45 |
| 40.0 | 16.0 | 0.4 | 50 |

**Fig. 7 Calculated minimum thickness for 37.5 mm diameter sample.**




(a) (b) (c)

**Fig. 8 (a-c): Coring layout to extract 100 mm and 56.0 mm diameter samples from 150 mm diameter.**

*2.4 Resilient Modulus Test Parameters*

All 75 samples from each diameter were grouped in 25 test matrices with 3 samples in each matrix having approximately equal average densities. This is to ensure consistency in the results obtained from the performance test. Inconsistency of density could affect the reliability of the test results.

The typical test parameters for the 100 mm diameter samples are 3,000 ms pulse width and a load setting of 1,200 N. All of the samples were tested at a pulse range 2,000 ms to 4,000 ms. A similar trend was adopted in selecting the loading range from 350 N-1,200 N. It was assumed that any loading above the standard 1,200 N load may take smaller samples beyond the elastic range causing permanent deformation. All of the 225 samples for the 3 different diameters were conditioned at 25 °C for 2 hours prior to testing.

The versatile Material Test Apparatus (MATTA) was used in the resilient modulus test in compliance with the ASTD 4123.

## 3. Results and Discussion

*3.1 Resilient Modulus Test on 100 mm Diameter Control Sample*

The results of the resilient modulus test for various loads and pulse for 100 mm diameter control samples are tabulated and shown in Table 3. The average of

**Table 3 Summary of resilient modulus (MPa), load (N) and pulse (ms) data for 100 mm diameter samples.**

| Load (N) | Pulse (ms) | $M_R$ (MPa) | Pulse (ms) | $M_R$ (MPa) | Pulse (ms) | $M_R$ (MPa) | Pulse (ms) | $M_R$ (MPa) | Pulse (ms) | $M_R$ (MPa) |
|---|---|---|---|---|---|---|---|---|---|---|
| 350 | 2,000 | 2,738 | 2,500 | 2,628 | 3,000 | 2,250 | 3,500 | 2,504 | 4,000 | 2,359 |
| 550 | 2,000 | 2,928 | 2,500 | 2,888 | 3,000 | 2,291 | 3,500 | 2,723 | 4,000 | 2,802 |
| 750 | 2,000 | 3,145 | 2,500 | 2,834 | 3,000 | 2,466 | 3,500 | 2,778 | 4,000 | 2,837 |
| 950 | 2,000 | 3,013 | 2,500 | 2,835 | 3,000 | 2,514 | 3,500 | 2,807 | 4,000 | 3,145 |
| 1,200 | 2,000 | 2,950 | 2,500 | 2,555 | 3,000 | 2,400 | 3,500 | 2,801 | 4,000 | 2,974 |

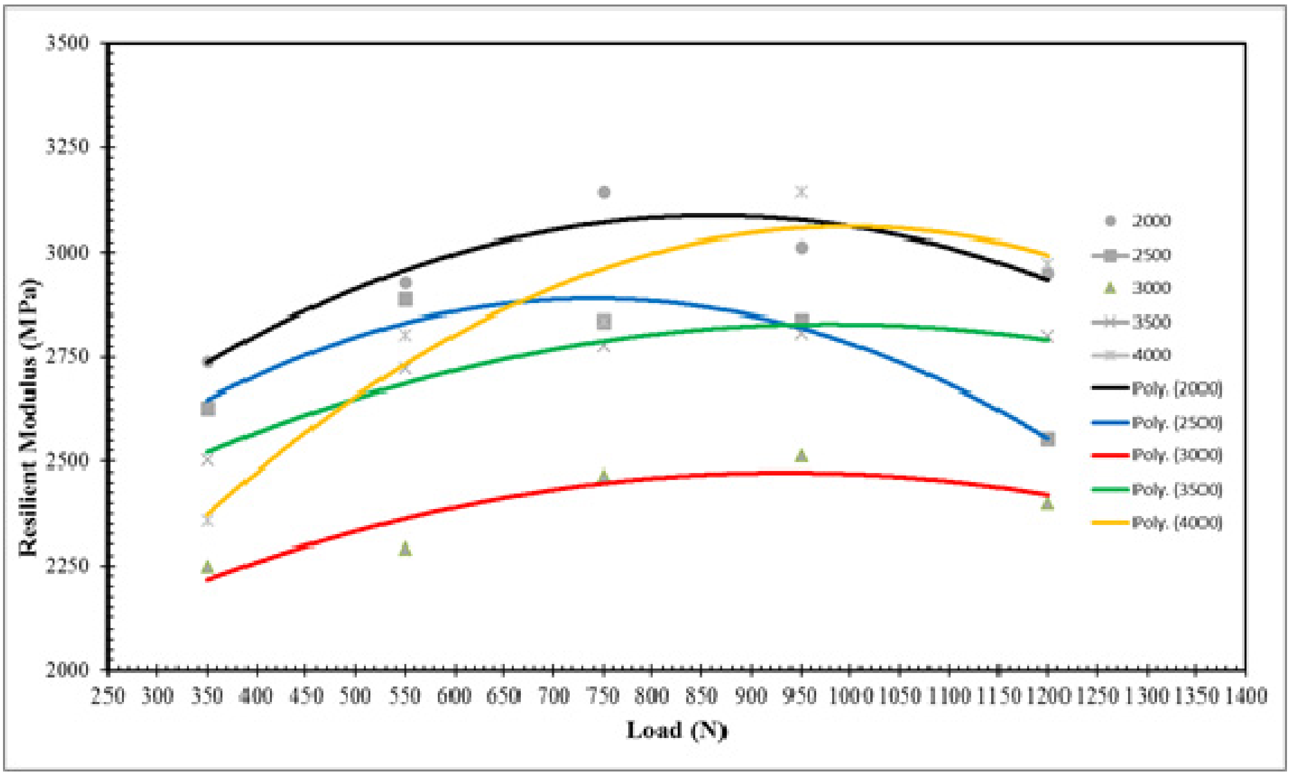



**Fig. 9 Resilient modulus for 100 mm diameter specimens versus load @ a pulse width of 2,000 ms, 2,500 ms, 3,000 ms, 3,500 ms and 4,000 ms.**

each 3 samples is shown. All of the samples displayed resilient modulus values from 2,250-3,150 MPa.

The resilient modulus values obtained from the test are as shown in Fig. 9. The highest resilient modulus is displayed by samples tested at about 900 N and 2,000 ms while the lowest is at about 950 N and 3,000 ms. This is an indication that the 100 mm diameter resilient modulus test values are quite close to the standard practice of using 1,200 N and 3,000 ms load and pulse width respectively. However, the challenge is to see if the performance level of the smaller samples can be correlated to the 100 mm diameter samples.

### *3.2 Resilient Modulus Test on 56.3 mm Diameter Miniature Sample*

The Resilient Modulus test performed using the MATTA machine is similar to the 100 mm diameter sample test above. The results of the resilient modulus test for 56.3 mm diameter samples are tabulated and shown in Table 4. It is observed that range of the resilient modulus is in the range of 2,588-3,753 MPa. From Fig. 10, it is observed that the highest resilient modulus values obtained are tested at about 900 N and 4,000 ms while the lowest at 850 N and 2,820 ms approximately. This is an interesting observation that, although the sample size is reduced in diameter by almost half, there seems to be some correlation as compared with the 100 mm diameter samples.

The resilient modulus values obtained from the test specimen were plotted against the various load settings. The plots are as shown in Fig. 10.

### *3.3 Resilient Modulus Test on 37.5 mm Diameter Miniature Sample*

A similar test was carried on the 37.5 mm diameter samples with the test matrix. The results of the resilient modulus test for the 37.5 mm diameter samples are tabulated and shown in Table 5. It is observed that the range of resilient modulus values is in the range of 2,060-5,250 MPa. From Fig. 11, it is observed that the highest values are tested at about 1,000 N and 3,000 ms while the lowest 850 N and 4,000 ms approximately. The 37.5 mm diameter samples showed a wide range of resilient.

**Table 4 Summary of resilient modulus (MPa), load (N) and pulse (ms) data for 56.3 mm diameter sample.**

| Load (N) | Pulse (ms) | $M_R$ (MPa) | Pulse (ms) | $M_R$ (MPa) | Pulse (ms) | $M_R$ (MPa) | Pulse (ms) | $M_R$ (MPa) | Pulse (ms) | $M_R$ (MPa) |
|---|---|---|---|---|---|---|---|---|---|---|
| 350 | 2,000 | 3,303 | 2,500 | 2,857 | 3,000 | 2,588 | 3,500 | 2,881 | 4,000 | 2,872 |
| 550 | 2,000 | 3,367 | 2,500 | 3,069 | 3,000 | 2,821 | 3,500 | 3,388 | 4,000 | 2,535 |
| 750 | 2,000 | 3,543 | 2,500 | 2,927 | 3,000 | 2,930 | 3,500 | 3,753 | 4,000 | 2,953 |
| 950 | 2,000 | 3,032 | 2,500 | 2,902 | 3,000 | 3,060 | 3,500 | 3,423 | 4,000 | 3,190 |
| 1,200 | 2,000 | 2,880 | 2,500 | 2,419 | 3,000 | 2,758 | 3,500 | 3,570 | 4,000 | 2,530 |

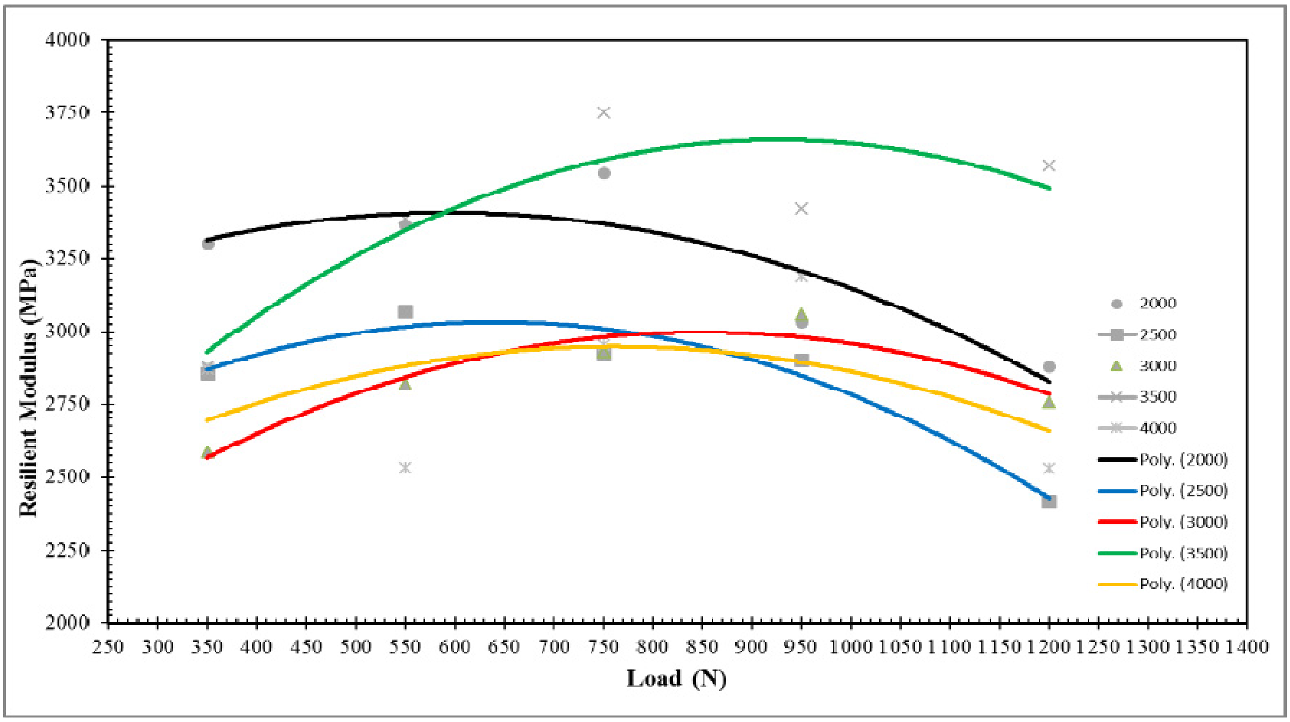



**Fig. 10 Resilient modulus for 56.3 mm diameter specimens versus various load and pulse width.**

**Table 5 Summary of resilient modulus (MPa), load (N) and pulse (ms) data for 37.5 mm diameter sample.**

| Load (N) | Pulse (ms) | $M_R$ (MPa) | Pulse (ms) | $M_R$ (MPa) | Pulse (ms) | $M_R$ (MPa) | Pulse (ms) | $M_R$ (MPa) | Pulse (ms) | $M_R$ (MPa) |
|---|---|---|---|---|---|---|---|---|---|---|
| 350 | 2,000 | 2,110 | 2,500 | 2,060 | 3,000 | 3,739 | 3,500 | 2,176 | 4,000 | 2,291 |
| 550 | 2,000 | 3,389 | 2,500 | 3,855 | 3,000 | 4,250 | 3,500 | 2,554 | 4,000 | 3,456 |
| 750 | 2,000 | 4,778 | 2,500 | 3,412 | 3,000 | 4,254 | 3,500 | 3,530 | 4,000 | 3,116 |
| 950 | 2,000 | 3,525 | 2,500 | 5,250 | 3,000 | 5,065 | 3,500 | 4,113 | 4,000 | 3,690 |
| 1,200 | 2,000 | 3,753 | 2,500 | 4,892 | 3,000 | 4,520 | 3,500 | 3,806 | 4,000 | 3,024 |

The resilient modulus obtained from the test specimen has been plotted as shown in Fig. 11.

From the plots as shown in Figs. 9-11, the optimum resilient modulus and optimum load values for sample diameter 100 mm, 56.3 mm and 37.5 mm are obtained using the quadratic equations of the individual plots. The optimum values are tabulated as shown in Table 6. The optimum values were used in establishing a correlation between the standard 100 mm diameter samples and the exploratory miniature sample sizes of 56.3 mm and 37.5 mm diameters.

The pulse versus load was plotted in a semi-log scale to see if there is any trend. It was observed that there is a trend between pulse width and load magnitude as can be seen in Fig. 12.

The linear equations as shown in Fig. 12 demonstrate a strong relationship between the three (3) types of specimen test results. The 100 mm diameter specimen results were correlated with the 56.3 mm diameter specimen and 37.5 mm diameter specimen. The load values at each pulse width were analyzed to identify the shift factors between 100 mm, 56.3 mm and 37.5 mm diameter specimens for various pulse widths. From the established linear Eq. (1), which represents the equation for 56.3 mm diameter specimen, a shift factor is introduced for each pulse width as shown

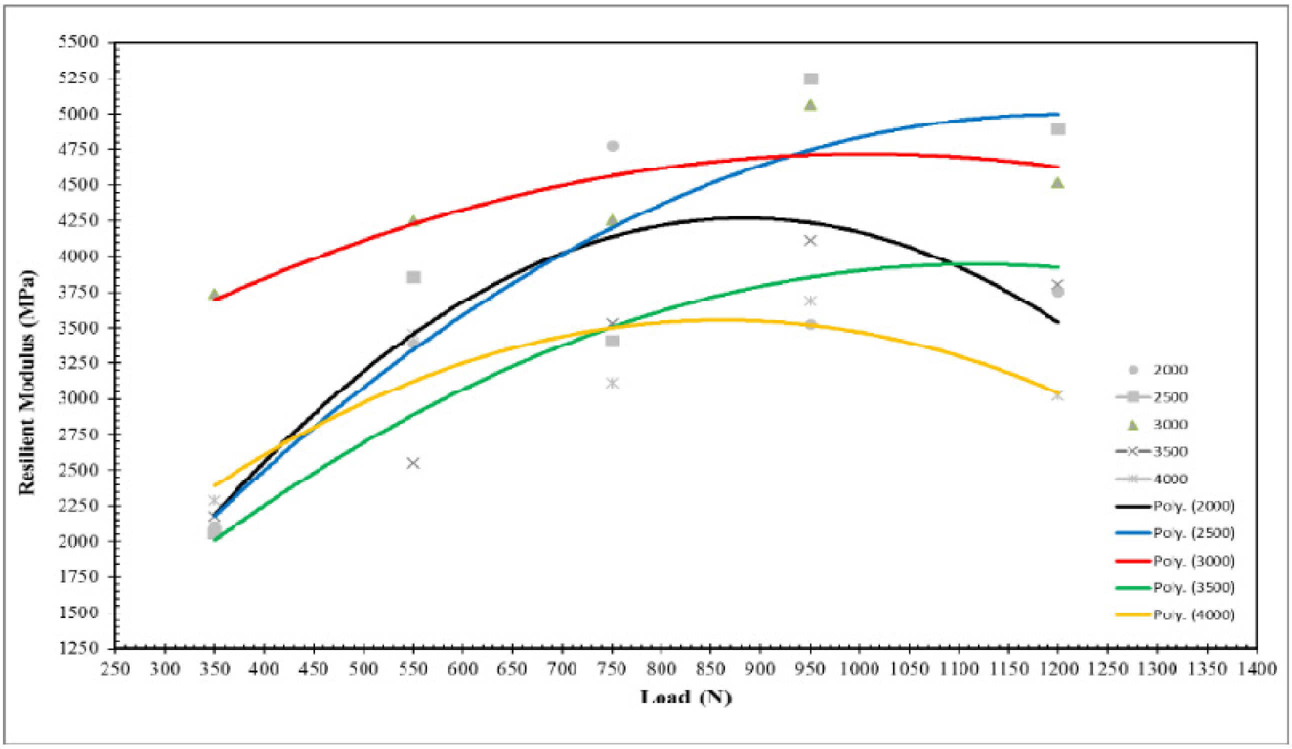



**Fig. 11 Resilient modulus for 37.5 mm diameter specimens versus various load and pulse width.**

**Table 6 Summary of optimum resilient modulus (MPa), optimum load (N) and pulse (ms) results for the various diameter specimens.**

| 100 mm Ø | | | 56.3 mm Ø | | | 37.5 mm Ø | | |
|---|---|---|---|---|---|---|---|---|
| Pulse (ms) | Load (N) | $M_R$ (MPa) | Pulse (ms) | Load (N) | $M_R$ (MPa) | Pulse (ms) | Load (N) | $M_R$ (MPa) |
| 2,000 | 888.92 | 3,119 | 2,000 | 583.75 | 3,398 | 2,000 | 883.49 | 4,267 |
| 2,500 | 733.75 | 2,881 | 2,500 | 667.11 | 3,027 | 2,500 | 1,190.81 | 4,932 |
| 3,000 | 878.44 | 2,434 | 3,000 | 862.50 | 3,017 | 3,000 | 1,000.71 | 4,711 |
| 3,500 | 923.56 | 2,790 | 3,500 | 920.57 | 3,645 | 3,500 | 1,115.76 | 3,945 |
| 4,000 | 1,023.53 | 3,103 | 4,000 | 760.20 | 2,948 | 4,000 | 869.92 | 3,587 |

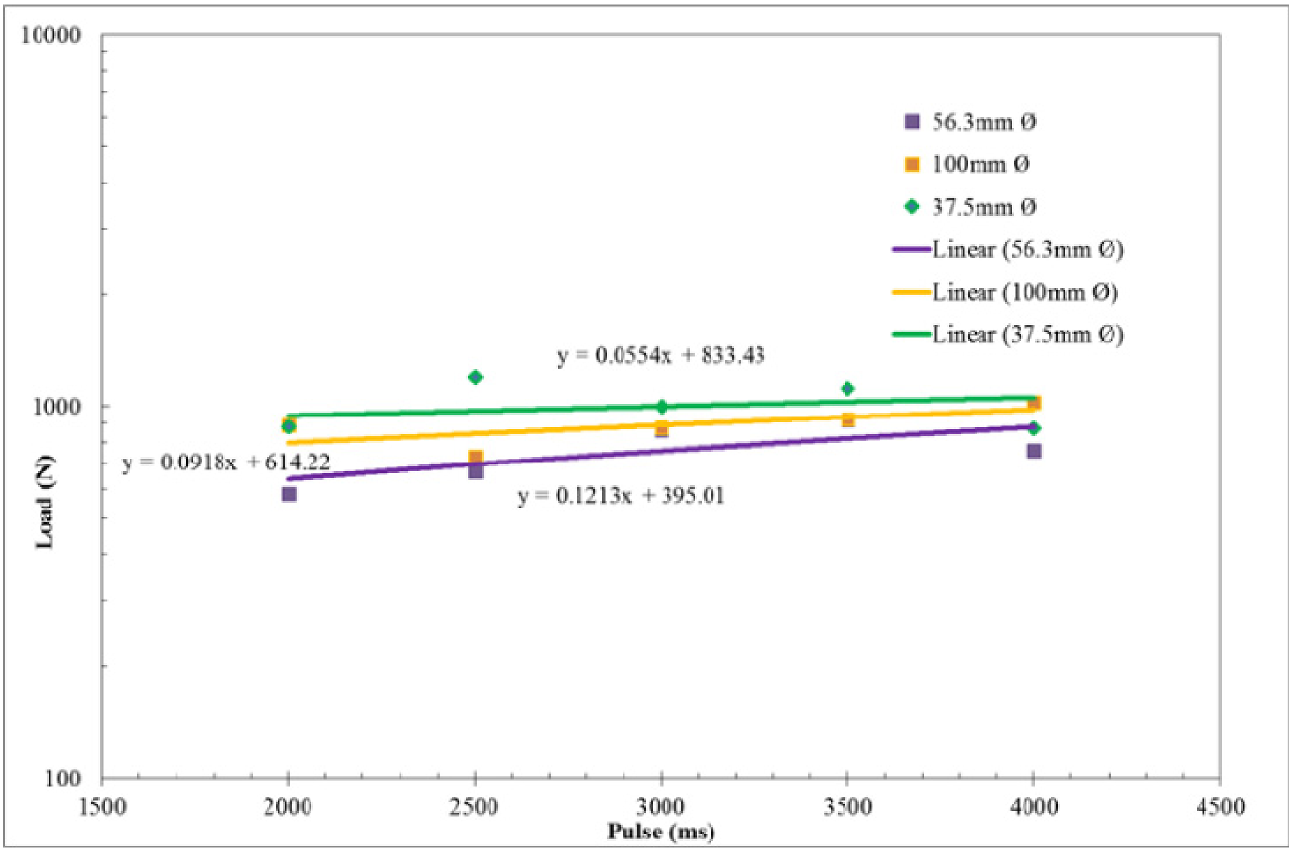



**Fig. 12 Correlations of load versus pulse for 100 mm, 56.3 mm & 37.5 mm diameter specimens.**

in Eq. (2) below. For instance, if a sample with 56.3 mm diameter is being tested at a pulse width of 3,000 ms, Eq. (5) is adopted to identify the appropriate load value to be used to begin the test. The shift factors are average of the initial and end values. The calculated shift factors are shown in the prediction equations below.

Equation:

$$y = 0.1213x + 395.01 \quad (1)$$

$$L_{56.3,\ \text{Pulse}} = [0.1213P + 395.01] * \textit{Shift Factor} \quad (2)$$

$$L_{56.3,\ 2000} = [0.1213P + 395.01] * 1.251 \quad (3)$$

$$L_{56.3,\ 2500} = [0.1213P + 395.01] * 1.208 \quad (4)$$

$$L_{56.3,\ 3000} = [0.1213P + 395.01] * 1.172 \quad (5)$$

$$L_{56.3,\ 3500} = [0.1213P + 395.01] * 1.141 \quad (6)$$

$$L_{56.3,\ 4000} = [0.1213P + 395.01] * 1.115 \quad (7)$$

where $P$ is the desired pulse to be tested at and $L$ is the recommended load.

From linear Eq. (8) which represents the equation for 56.3 mm diameter specimen, a shift factor is introduced for each pulse width as shown in Eq. (9). Again, if a sample with 37.5 mm diameter is being tested at a pulse width of 3,000 ms, Eq. (12) can be adopted to identify the appropriate load value to be used in the newly established protocol using prediction equations.

Equation:

$$y = 0.0554x + 833.43 \quad (8)$$

$$L_{37.5,\ \text{Pulse}} = [0.0554P + 833.43] * \textit{Shift Factor} \quad (9)$$

$$L_{37.5,\ 2000} = [0.0554P + 833.43] * 0.845 \quad (10)$$

$$L_{37.5,\ 2500} = [0.0554P + 833.43] * 0.868 \quad (11)$$

$$L_{37.5,\ 3000} = [0.0554P + 833.43] * 0.890 \quad (12)$$

$$L_{37.5,\ 3500} = [0.0554P + 833.43] * 0.911 \quad (13)$$

$$L_{37.5,\ 4000} = [0.0554P + 833.43] * 0.930 \quad (14)$$

where $P$ is the desired pulse to be applied and $L$ is the recommended load.

### *3.4 Validation Work*

To verify the preliminary findings, several samples of 100 mm, 56.3 mm and 37.5 mm diameters were prepared in accordance with the procedure mentioned

**Table 7 Validation and variance.**

| Pulse (ms) | Load (N) | 100 mm | 56.3 mm | | 37.5 mm | |
|---|---|---|---|---|---|---|
| | | $M_R$ (MPa) | $M_R$ (MPa) | Variation % | $M_R$ (MPa) | Variation % |
| 2,000 | 800 | | 2,318 | 5.48 | 2,384 | 2.79 |
| 2,500 | 845 | | 2,401 | 2.11 | 2,321 | 5.37 |
| 3,000 | 890 | 2,453 | 2,433 | 0.82 | 2,418 | 1.43 |
| 3,500 | 950 | | 2,430 | 0.94 | 2,417 | 1.44 |
| 4,000 | 985 | | 2,407 | 1.85 | 2,293 | 6.52 |
| | | | | Average is 2.24 | | Average is 3.51 |

in materials and method. The required loads for the 5 different pulses from 2,000-4,000 ms were determined using the established equations. The load parameters were adjusted to the nearest values as shown in Table 7. The test results are as shown in the same table. It can be observed that, the resilient modulus values obtained for 56.3 mm as compared with that of the 100 mm samples are very close and the average variation is about 2.24% while the 37.5 mm diameter sample values are quite close as compared with the 100 mm diameter samples but had a higher variation of about 3.51%.

## 4. Conclusion

Based on this preliminary research work, it can be concluded that smaller core specimens may be used to test for resilient modulus. The validation analysis showed that the 56.3 mm diameter samples' resilient modulus values are very close to the 100 mm diameter sample resilient modulus value with a variance of about 2.24% only. The 37.5 mm samples displayed a variation of about 3.51% as compared with the 100 mm sample value. The developed prediction regression equations as mentioned in Results and Discussion may be used to determine the loads required to test the miniature samples. As the pavement industries in many countries are moving towards practicing thin overlay pavement as to minimize the rehabilitation cost, this study could be of importance and very beneficial in conducting the performance test on specimens directly cored from field thin overlay and wearing course layers. It was also observed that the amount of asphalt and aggregate materials needed to carry out mix designs and advanced performance tests were reduced.

## References

[1] Hamzah, M. O. 2009. "Effects of Temperature and Binder Type on the Dynamic Creep of Asphaltic Concrete Incorporating Geometrically Cubical Aggregates Subjected to Ageing." *Modern Applied Science* 3 (7): 3-14.

[2] Hassim, S., Harahap, R., Muniandy, R., Kadir, M., and Mahmud, A. 2005. "Cost Comparison between Stone Mastic Asphalt and Asphalt Concrete Wearing Course." *American Journal of Applied Sciences* 2 (9): 1350-5.

[3] Mansour, T. N., Putman, B. J., and Asce, A. M. 2013. "Influence of Aggregate Gradation on the Performance Properties of Porous Asphalt Mixtures." *Journal of Materials in Civil Engineering* 25 (2): 281-8.

[4] Oh, J. H., Fernando, E. G., Holzschuher, C., and Horhota, D. 2012. "Comparison of Resilient Modulus Values for Florida Flexible Mechanistic-Empirical Pavement Design." *International Journal of Pavement Engineering* 13 (5): 472-84.

[5] Kandhal, P. S. 1991. "Design of Large-Stone Asphalt Mixes for Low Volume Roads Using 6-in. Diameter Marshall Specimens." *Transportation Research Record* 1291: 253-62.

[6] Muniandy, R., and Bujang, B. K. H. 2006. "Laboratory Diameteral Fatigue Performance of Stone Matrix Asphalt with Cellulose Oil Palm Fiber." *American Journal of Applied Science* 3 (9): 2005-10.

[7] Yousif, R. A., Muniandy, R., Hassim, S., Jakarni, F. M., and Aburkaba, E. 2015. "An Overview of Quantification of Fatigue Resistance of Asphalt Mixture Using Pre-aged Binder." *WALIA Journal* 31: 125-32.

[8] Moazami, D., Behbahani, H., and Muniandy, R. 2011. "Pavement Rehabilitation and Maintenance Prioritization of Urban Roads Using Fuzzy Logic." *Expert Systems with Applications* 38 (10): 12869-79.

[9] Jahromi, S. G., and Khodaii, A. 2009. "Comparing Factors Affecting Resilient Modulus in Asphalt Mixtures."

*Transaction A: Civil Engineering* 16 (5): 367-75.

[10] Pavlovich, R. D., and Goetz, W. H. 1976. “Direct Tension Test Results for Some Asphalt Concretes.” *Journal of the Association of Asphalt Paving Technologist* 45: 400-28.

[11] Arabani, M., and Ferdowsi, B. 2009. “Evaluating the Semi-circular Bending Test for HMA Mixtures.” *International Journal of Engineering, Transactions A: Basics* 22 (1): 47-58.

[12] Muniandy, R., Aburkaba, E. E., Hamid, H., and Yunus, R. B. T. 2009. “An Initial Investigation of the Use of Local Industrial Wastes and By-Products as Mineral Fillers in Stone Mastic Asphalt Pavements.” *Journal of Engineering and Applied Sciences* 4 (3): 54-63.

[13] Loulizi, A., Flintsch, G. W., and Mcghee, K. 2007. “Determination of In-Place Hot-Mix Asphalt Layer Modulus for Rehabilitation Projects by a Mechanistic-Empirical Procedure.” *Transportation Research Record* 2037 (1): 53-62.

[14] Patel, A., Kulkarni, M. P., Gumaste, S. D., Bartake, P. P., Rao, K. V. K., and Singh, D. N. 2011. “A Methodology for Determination of Resilient Modulus of Asphaltic Concrete.” *Advances in Civil Engineering*, 1-6.

[15] Muniandy, R., Jakarni, F. M., Hassim, S., and Mahmud, A. R. 2008. “A Newly Developed Laboratory Slab Roller Compactor (Turamesin): An Overview.” *International Journal of Engineering, Transactions A: Basics* 21 (2): 133-42.